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Epoxy resin admixture for concrete

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EPOXY RESIN ADMIXTURE FOR CONCRETE

BY

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A

THESIS

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ABSTRACT

This thesis describes laboratory tests on concrete having epoxy as an admixture. Cylinders for compression and elastic modulus tests were cured under two different curing conditions, standard laboratory cure and a simulated job cure. Beams cured under laboratory conditions were tested for flexural strength.

Test results show the compressive strength increases with an increase of epoxy content for job curing conditions. However, compressive and flexural strengths of specimens cured under laboratory conditions show a slight decrease. The elastic modulus of concrete containing epoxy also decreases in comparison to ordinary concrete.

ACKNOWLEDGEMENT

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I. INTRODUCTION

Since its introduction to this country, epoxy resin has found a position in the concrete construction field because of its high compressive and tensile strengths as well as excellent adhesive properties. In recent years most of the applications have been in bonding concrete to concrete in repairing damaged or deteriorated construction. Therefore, studies and applications have been concentrated on its adhesive properties. Engineers, of course, have been aware of its high strength but little research has been done in this direction.

Although epoxy concrete, in which epoxy resin compound replaces cement paste, possesses high compressive and tensile strengths; it has not been widely used in concrete construction despite its outstanding properties. The high cost of epoxy resin definitely limits the use of epoxy concrete since the cost of epoxy concrete is of the order of $200 per cubic yard (5). Only the repair of bridges subject to heavy traffic can justify its application because of its fast setting properties; the repaired bridges can be opened to traffic after only a few hours.

Although higher strength concrete can be produced by other means, the partial replacement of the cement paste with epoxy was considered worth exploring in order to see if some of the properties of the pure epoxy concrete would be retained.

In this investigation, the tests were planned to determine the effect of epoxy content upon the compressive strength, modulus of rupture, and the modulus of elasticity. Curing conditions were specified to include both a standard laboratory cure and a simulated job cure.

II. HISTORY AND REVIEW OF LITERATURE

The discovery of epoxy was first reported in 1891 by the Norwegian scientist, Lindeman (1). Subsequent to that time, the use of epoxy was limited to laboratory investigations until industrial applications of epoxy resins were begun in Germany in the Thirties. During World War II, Germany made practical use of epoxy by using it to stick treads to their tanks.

Epoxy resins were first introduced in the United States in 1949 (4). As commercial quantities became available, it was primarily used by the paint industry in heavy-duty industrial maintenance paints, and by the aircraft industry as a structural adhesive to bond aluminum to aluminum. However, it was not used in concrete construction until the California State Highway Department used epoxy adhesives to cement reflective traffic markers to pavements in 1954 (5). These markers have withstood heavy traffic for five years without failure in bond. They also found that when an epoxy resin was mixed with flexibiliser the mixture would bond to hardened concrete and also that fresh concrete would adhere to it if applied while the epoxy mixture was still tacky. Since then, much work has been done by manufacturers, government agencies, and others in perfecting epoxy resin systems for application in concrete construction and repair.

Bailey Tremper (3) described in his paper the use of adhesives and binders containing epoxy resins by the California Division of Highways in repairing concrete. In patching spalled areas with epoxy mortar or epoxy concrete, the binder used by the California Division of Highways has a pot life of about 20 minutes at 70°F. Under favorable conditions the repair has been opened to traffic within 3-5 hours. The ratio of epoxy binder to sand used by the California Division of Highways is of the order of 1 to 7 by weight. For large volume repairs, both coarse and fine aggregates are used and the ratio of epoxy binder to aggregate can be as large as 1:18 by weight.

The formulation most frequently used by the California Division of Highways both for an adhesive and a binder consists of:

Epoxy resin	10 parts by weight
Polysulfide polymer	4 parts by weight
Curing agent	1 part by weight
Filler	Variable

Elliott N. Dorman and M. M. Gruber (6) have shown that concrete pipe for sewers can be coated with epoxy. The resistance of these coatings to sewage, chemicals, fumes and hydrostatic pressure assures long life and maintenance-free service.

Surfacing compounds with a high friction coefficient are of considerable importance on superhighways and heavily traveled bridges (6). Because of its high adhesive properties, epoxy resin is used as a binder for high-friction aggregate and as an adhesive to bond it to the pavement. Such binders must also be tough enough to withstand continuous abrasion from heavy vehicles being breaked at high speed.

Epoxy resin is also used in chemical resistant floor topping; it is the bonding agent that holds the topping together and binds it to the floor (7). This floor topping protects concrete floors subjected to acids, strong alkalies and solvents that react with cement.

Tests on epoxy have been conducted by Leo Carbett (1), Director of Research of Great Western Corp. of Los Angeles. In the Great Western Laboratory, epoxy test cylinders were immersed in sulphuric acid which dissolves steel in minutes. Due to their excellent chemical resistant properties, they have survived after one week of immersion. Other tests showed that the bond strength as an adhesive was greater than that of concrete. Broken beams cemented together by epoxy resin compound were loaded to failure in flexure. Rupture always occurred in the concrete, not in the adhesive bond.

In 1962, a report (4) was published by A.C.I. Committee 403 describing proper procedures for the use of epoxy resin compounds for various purposes. Methods for specific applications outlined by the Committee include patching, crack and joint sealing, water-proofing, skid resistant overlays, bonding hardened concrete to hardened concrete, bonding new concrete to old concrete. It is emphasized that before attempting the application of epoxy resin compound, surface conditions must be met. The surface on which epoxy is applied must be strong, clean and dry.

G. B. Welch, A. J. Carmichael and D. E. Hattersley (2) of the University of New South Wales, Australia conducted a series of tests on the compressive strength, tensile strength and other properties of epoxy concrete. Four different types of epoxy formulations were examined as the cementing material in the concrete mixtures and each type of epoxy formulation had one to four different proportions of aggregates. Test results showed that ultimate compressive strengths ranged from 7,000 psi to 13,000 psi while tensile strength exceeded 1200 psi.

III. EPOXY RESIN SYSTEMS

A. RESINS

Uncured epoxy resins are water insoluble, clear plastics, which in the pure and uncontaminated state possess indefinite shelf life. The grades of epoxy resins are generally specified by viscosity and epoxide equivalent. The viscosity of an epoxy system can be reduced by adding diluents, but the use of diluents should be held to a minimum as, in most cases, they degrade the physical properties of the cured system.

Epoxy resins belong to a class of thermosetting materials which requires an external influence to convert them to a stable solid mass. The systems which are of concern here are generally furnished in two components; resin and curing agent. When the curing agent is added to the resin, a curing reaction commences, and the conversion to a solid occurs. Oftentimes, other materials are added to alter the physical characteristics of the cured system.

Unlike thermoplastic materials, thermosetting epoxy resins become permanently hard once they cure and will not melt at elevated temperatures. Cured epoxy resins are characterized by possessing low chemical reactivity, remarkable adhesive properties, and high strengths. They can have ultimate compressive strengths of 30,000 psi, flexural strengths up to 18,000 psi and tensile strengths varying from 8,000 to 12,000 psi (3).

Epoxy resins as presently manufactured, are available in a wide range of consistencies ranging from a solid to liquids of relatively low viscosity. There are four manufacturers in the United States producing epoxy resins. They are the Bakelite Company, Ciba Products Company, Jones-Dabney Company and Shell Chemical Company. Each of these manufacturers has his own trade name for these products.

B. CURING

Curing agents are necessary to effect the conversion of the pure epoxy resin to a solid. This conversion is accompanied by a production of heat. Since the curing process is rapidly accelerated by higher temperatures, large batches will harden faster than small ones with similar geometry due to the decrease in the rate of heat loss from the large mass.

After adding curing agent to the epoxy, thorough mixing is most important. Once the components are mixed, they must be used within a relatively short time. The time that a mixture remains in a usable or workable condition after mixing is called the "pot life". The pot life of an epoxy resin compound depends on the formulation, the type of curing agent used, and also its mass and temperature. The use of shallow containers will reduce the heat build-up; hence, increase the pot life. Curing temperatures for the usual epoxy formulations are between 50°F and 85°F. Curing below 50°F is greatly retarded or stops. Above 85°F the cure is greatly accelerated and the pot life critically shortened.

IV. LABORATORY PROCEDURE

A. TEST APPARATUS

1. Sieves And Sieve Shakers

Two types of mechanical sieve shakers were used for screening the coarse and fine aggregates. A large shaker, a product of Gibson Screen Company, Merser, Pennsylvania, was used to screen the coarse aggregate. A set of wire screens 17" x 25" in dimension with the following opening sizes was used: 1", 3/4", 1/2", 3/8", No. 4 and No. 8.

For screening the fine aggregate, a small shaker having a set of sieves 8" in diameter made by W. S. Tyler Company, Cleveland, Ohio was used. The mesh opening sizes of sieves are 3/8", No. 4, No. 8, No. 16, No. 30, No. 50 and No. 100.

2. Concrete Mixer

The concrete mixer, Type SW153, has a capacity of three cubic feet. It is a product of the Lancaster Iron Works Inc., Lancaster, Pennsylvania. This mixer is stationary, nontilting, and electrically driven.

3. Compression Testing Machines

Two hydraulic compression machines were used for the tests. A machine made by Forney's Inc., New Castle, Pennsylvania, was used for all compression cylinder tests.

This machine has two scales, the low range of 0-60,000 pounds with 200 pound graduations and the high range of 0-350,000 pounds with 1000 pound graduations.

A Riehle compression machine was used for determining the flexural strengths. It has a platform 30 1/2 x 32" in dimension. The size of the platform enables small beams to be tested. The 0-3,000 pound scale is capable of being read to the nearest 5 pounds.

4. Los Angeles Abrasion Testing Machine

The Los Angeles Abrasion Testing Machine is a product of Forney's Inc., New Castle, Pennsylvania. It consists of a hollow steel cylinder, closed at both ends having an inside diameter of 28 inches and inside length of 20 inches. This electrical driven machine was used to mix the epoxy resin and fine aggregate before placing in the concrete mixer.

5. Ames Dial Gage

An Ames dial was used to measure the deformation of the compression cylinders in the test for modulus of elasticity. The dial gage was made by Standard Gage Co. Inc., Poughkeepsie, New York and had a minimum graduation of 0.001 inch.

B. MATERIALS USED IN TESTS

1. Cement

The cement used in all mixes was commercial portland cement Type 1 Red Ring, and was obtained from the Missouri Portland Cement Company, Kansas City, Missouri.

2. Aggregate

The coarse aggregate used in all mixes was crushed white limestone from Springfield, Missouri and was supplied by C. F. Farney of Rolla. The specific gravity of the coarse aggregate was 2.65. The sieve analysis was conducted in accordance with "Standard Method of Test for Sieve Analysis of Coarse and Fine Aggregate". ASTM Designation C 136 and the results were as follows:

Sieve Size	Percent Passing
1 inch	100
3/4 inch	95
1/2 inch	47.5
3/8 inch	20
No. 4	2.5
No. 8	0

The ASTM Designation C-33, specification for 3/4" coarse aggregate gradation is as follows:

Sieve Size	Percent Passing
1 inch	100
3/4 inch	90 - 100
3/8 inch	20 - 55
No. 4	0 - 10
No. 8	0 - 5

The results obtained from the sieve analysis showed that the coarse aggregate used in the mixes met the requirement of the ASTM specification.

The fine aggregate was obtained from the Meramec River Sand and Gravel Company, Pacific, Missouri. The specific gravity of the fine aggregate was 2.65. The sieve analysis was performed in accordance with the "Standard Method of Test for Sieve Analysis of Coarse and Fine Aggregate" ASTM Designation C 136 and the results were as follows:

Sieve Size	Percent Passing
3/8 inch	100
No. 4	99
No. 8	82
No. 16	66
No. 30	55
No. 50	18
No. 100	3

The ASTM Designation C-33, Specification for fine aggregate gradation is as follows:

Sieve Size	Percent Passing
3/8 inch	100
No. 4	95 - 100
No. 8	80 - 100
No. 16	50 - 85
No. 30	25 - 60
No. 50	10 - 30
No. 100	2 - 10

The results from the sieve analysis showed that the fine aggregate used met the requirement of the ASTM specification. The fineness modulus calculated was 2.77.

3. Water

The water used in the mixes was ordinary water obtained from the University of Missouri.

4. Admixture

The epoxy resin used as an admixture was Ciba Araldite 6010 (diglycidyl ether of bisphenol A). It was produced by the Ciba Products Company, Fair Lawn, New Jersey. It is a water insoluble, transparent, thermosetting material in liquid form having an epoxy equivalent of 195, and a viscosity of 160 poises at 25 degrees C. The curing agent used was Ciba Hardener 951 (triethylene tetramine).

The formulation of the epoxy resin system used in the tests was 100 parts of resin and 20 parts of curing agent by weight.

C. MIXING PROCEDURE

1. Design Of The Mixtures

Since it was thought that the effect of the epoxy would be related to the fraction of voids filled, the epoxy content was expressed as a percentage of the void volume or cement paste. In order to keep the volume of epoxy to a minimum, a lean mix was used since this produced a smaller void ratio.

In addition, since a lean mix has a lower strength than a rich mix, a change in strength was easier to detect with the lean mix used as a basis of comparison.

Three mixes of concrete, each with a different percentage of epoxy resin compound were made. The percentages of epoxy resin compound were zero, four and eight per cent of the volume of cement paste and these three mixes were designated as Mix A, B and C respectively. The amount of epoxy resin compound used was equal to the volume of cement paste removed. This means that the volume of cement paste plus epoxy resin compound was constant for all mixes. Mix D was the same as Mix C except that the mixing procedure was changed. The amount of ingredients of the mixes was calculated in accordance with "Design and Control of Concrete Mixtures", published by Portland Cement Association (see Table 1).

2. Mixing Concrete

A three cubic foot batch was used for Mix A, B and C. The usual mixing procedure followed for Mix A was:

(1) add coarse aggregate to the mixer,

(2) add fine aggregate,

(3) add cement,

(4) add water,

(5) mix for two minutes.

On the other hand, due to the presence of epoxy resin and curing agent, a different procedure was set up for Mix B

TABLE I. CONCRETE MIX DESIGN*

Type of Mix	Coarse Aggregate (lb.)	Fine Aggregate (lb.)	Cement (lb.)	Water (lb.)	Epoxy Resin (lb.)	Curing Agent (lb.)
Mix A	1620	1690	427	302	—	—
Mix B	1620	1690	410	290	16.4	3.3
Mix C	1620	1690	393	278	32.8	6.6
Mix D	1620	1690	393	278	32.8	6.6

* Basis: 1 cubic yard of concrete

Maximum size of aggregate = 3/4"

F. M. of sand = 2.77

Water per sack of cement = 8 gal.

Slump = 1 1/2"

and C as follows:

(1) Thorough mixing of fine aggregate with epoxy in advance was necessary. This was done, for Mix B, by adding the epoxy resin to fine aggregate and mixing in a Los Angeles Abrasion Testing Machine. After mixing for thirty minutes, this sand-epoxy mixture was transferred to the concrete mixer for further mixing because epoxy lumps still could be seen in the Los Angeles Abrasion Testing Machine. For Mix C, epoxy resin and fine aggregate and some coarse aggregate were mixed directly in the concrete mixer. Only seven minutes were required to produce a thorough mixing for Mix C.

(2) After the epoxy lumps were eliminated in step 1, approximately half of the coarse aggregate was added to the mixer and mixed for five more minutes. The addition of coarse aggregate helped to produce more thorough mixing of epoxy resin and aggregate.

(3) The rest of the coarse aggregate and cement was added.

(4) The curing agent was added to the water, and then the premixed curing agent and water and cement were added to concrete mixer.

(5) Mixing was continued for two minutes.

However, the mixing procedure for Mix D was changed from that of Mix B and C in order to determine if any different results would be obtained. In Mix D epoxy resin was mixed thoroughly with the curing agent before being added to the fine aggregate. The epoxy and sand were mixed for two minutes in the concrete mixer, and then half of the coarse aggregate was added and mixed for three minutes. The rest of the coarse aggregate, cement and water was then added and mixing was continued for two minutes.

3. Handling Precautions

The curing agents employed in epoxy resin formulations are strong skin irritants. These materials can produce local injury on very short exposure and may even cause permanent bodily injury after prolonged exposure. Therefore, epoxy resin plus curing agent in the uncured state should be handled with care. It is emphasized that direct skin contact must be avoided. Glasses and rubber gloves should be worn in handling these materials. If it should contact the skin, it should be removed immediately by washing the contaminated area thoroughly with soap and water.

D. TEST PROCEDURE

1. Test Procedure For Compressive Strength

Forty-two cylinders were cast from four batches of concrete with different percentages of epoxy resin compound. Mix A consisted of eighteen cylinders from two batches. Mix B and C consisted of twelve cylinders, each set being cast from one batch. 6" x 12" cylinders were cast in paraffined paper molds with metal bottoms. They were placed in the curing room which was maintained at 70°F and

100 per cent relative humidity. After three days, half of the cylinders were removed from the curing room and were kept outside the curing room until the proper age for testing. This was done to simulate job curing conditions.

The tests were performed in accordance with the "Standard Method of Test for Compressive Strength of Molded Concrete Cylinders", ASTM Designation C-39. Cylinders were tested at ages of 7, 14 and 28 days. They were capped with a sulphur compound before the test. All cylinders were loaded to failure and the ultimate loads were recorded. The compressive strength of the specimen was calculated by dividing the ultimate load by the cross-sectional area of the specimen

$$f = \frac{P}{A}$$

where

f = unit stress in pounds per square inch

P = ultimate load in pounds

A = cross-sectional area of the cylinder in square inches

The procedure was the same for testing at various ages. At the age of 28 days, the modulus of elasticity was also determined simultaneously with the compression test.

2. <u>Test Procedure for Flexural Strength</u>

Seven 3 1/2" x 4 1/2" x 18" beams were cast for the flexural strength tests from three batches, each with a different percentage of epoxy resin compound. Mix A consisted of three beams while Mix B and Mix C each consisted of two beams. Beams were placed in the curing room which was maintained at 70°F and 100 percent relative humidity. All beams remained in the curing room for 28 days.

The tests were conducted in accordance with the "Standard Method of Test for Flexural Strength of Concrete Using Simple Beam with Center-Point Loading", ASTM Designation C293. A Riehle compression Testing Machine was used in performing the beam tests. The 0-3,000 pound scale was used and the beams were supported over a span of 15". The load was applied at the center of the beam at a rate of 2 psi per second in terms of maximum fiber stress.

The beams were loaded to failure and the ultimate loads were recorded. The modulus of rupture was calculated as follows:

$$R = \frac{3PL}{2bd^2}$$

where

R = modulus of rupture in pounds per square inch

P = maximum applied load in pounds

L = span length in inches

b = width of specimen in inches

and d = depth of specimen in inches

In the calculations the weight of the specimen was neglected.

3. Test Procedure For Modulus of Elasticity

Tests for modulus of elasticity were made simultaneously with compression tests at 28 days. Fourteen compression test cylinders, six from Mix A, four from each of Mix B and C were tested and results obtained for both laboratory curing conditions and job curing conditions.

An Ames dial held by a stand was placed against the lower platform of the testing machine to measure the deformation of the concrete cylinder under load. Deformations and loading at intervals of ten kips were read.

The secant modulus of elasticity was determined by the ratio of stress, taken at 50 per cent of the ultimate strength, to strain. The elastic modulus for 6" x 12" cylinders is given by the equation

$$E = 0.424 \frac{P}{\Delta}$$

where

E = modulus of elasticity in pounds per square inch

P = applied load in pounds

Δ = total deformation in inches

V. TEST RESULTS AND DISCUSSION

A. PROPERTIES OF FRESH CONCRETE

The effect of admixture on the properties of fresh concrete was not very large. The slump for the two batches of Mix A was 1 1/2" and 1". The slumps for Mix B, Mix C and Mix D were 2", 1 1/2" and 1 1/2" respectively. The test results show that there is no appreciable change in slump due to the increase in percentage of admixture.

Laboratory observations indicate that the tendency of water to collect on the tops of the specimens decreases with an increase in percentage of admixture. This may be caused, in part, by the epoxy plugging the gaps between aggregate particles.

B. COMPRESSIVE STRENGTH TEST

The results of the compressive tests are shown in Figures 1 to 4. Figure 1 shows the relation between percentage of admixture used and compressive strength at the ages of 7, 14 and 28 days under laboratory curing conditions. Figure 2 shows the relation between percentage of admixture used and compressive strength at the ages of 7, 14 and 28 days under job curing conditions. In Figures 3 and 4, compressive strength was plotted against age for Mix A, B, C and D in order to have a clear comparison.

Under laboratory curing conditions, the average stress at 7 days of Mix B and C specimens is 106 per cent of Mix A which has no admixture. The compressive stress at 14 days of Mix B and C is 90 per cent and 103 per cent of Mix A respectively. At the age of 28 days, the strength of Mix B and C specimens is 90.5 per cent and 98 per cent of Mix A.

Under job curing conditions, the average compressive stress at 7 days of Mix B and C specimens is 116 per cent and 118 per cent of Mix A respectively. The compressive stress at 14 days of Mix B and C is 119 per cent and 131 per cent of Mix A. At the age of 28 days, the strength of Mix B and C is 108 per cent and 121 per cent of Mix A. The increase in compressive strength due to the increased amount of admixture under job curing conditions is nearly linear at the ages of 14 and 28 days. However, the results indicate that the compressive strength at 14 and 28 days of Mix B under laboratory curing conditions decreased with respect to Mix A. This reduction in compressive strength is probably due to the exposure of specimens to moisture during the curing procedure. Moisture may affect the curing of epoxy resin.

C. FLEXURAL STRENGTH TEST

The results of the tests on flexural strength of beams are shown in Figure 5. This Figure shows the relation between modulus of rupture at the age of 28 days and percentage of admixture used. The average strength of specimens of Mix B and C is 81.5 per cent and 93.5 per cent of Mix A respectively.

Because all beams were placed in the curing room until the time for testing, the decrease in flexural strength is also apparently due to the presence of moisture during curing. The curve plotted for modulus of rupture vs. percentage of admixture follows the same pattern of that for compressive strength under laboratory curing conditions.

D. MODULUS OF ELASTICITY TEST

The results of modulus of elasticity tests on compression cylinders are shown in Figures 6 and 7. In the Appendix, Figures 8, 9, and 10 show the stress-strain curve for Mixes A, B and C respectively under laboratory curing conditions. Figures 11, 12, and 13 show the stress-strain curve for Mixes A, B and C respectively under job curing conditions.

The secant modulus of elasticity was determined at 50 per cent of the ultimate stress. The modulus of Mix B and C specimens under laboratory curing conditions is 95 per cent and 91 per cent respectively of Mix A and decreases linearly with increase of percentage of admixture. The elastic modulus of the Mix B and C specimens under job curing conditions is 78 per cent and 84 per cent respectively of Mix A. The decrease in elastic modulus is probably due to the low elastic modulus properties of epoxy resin.

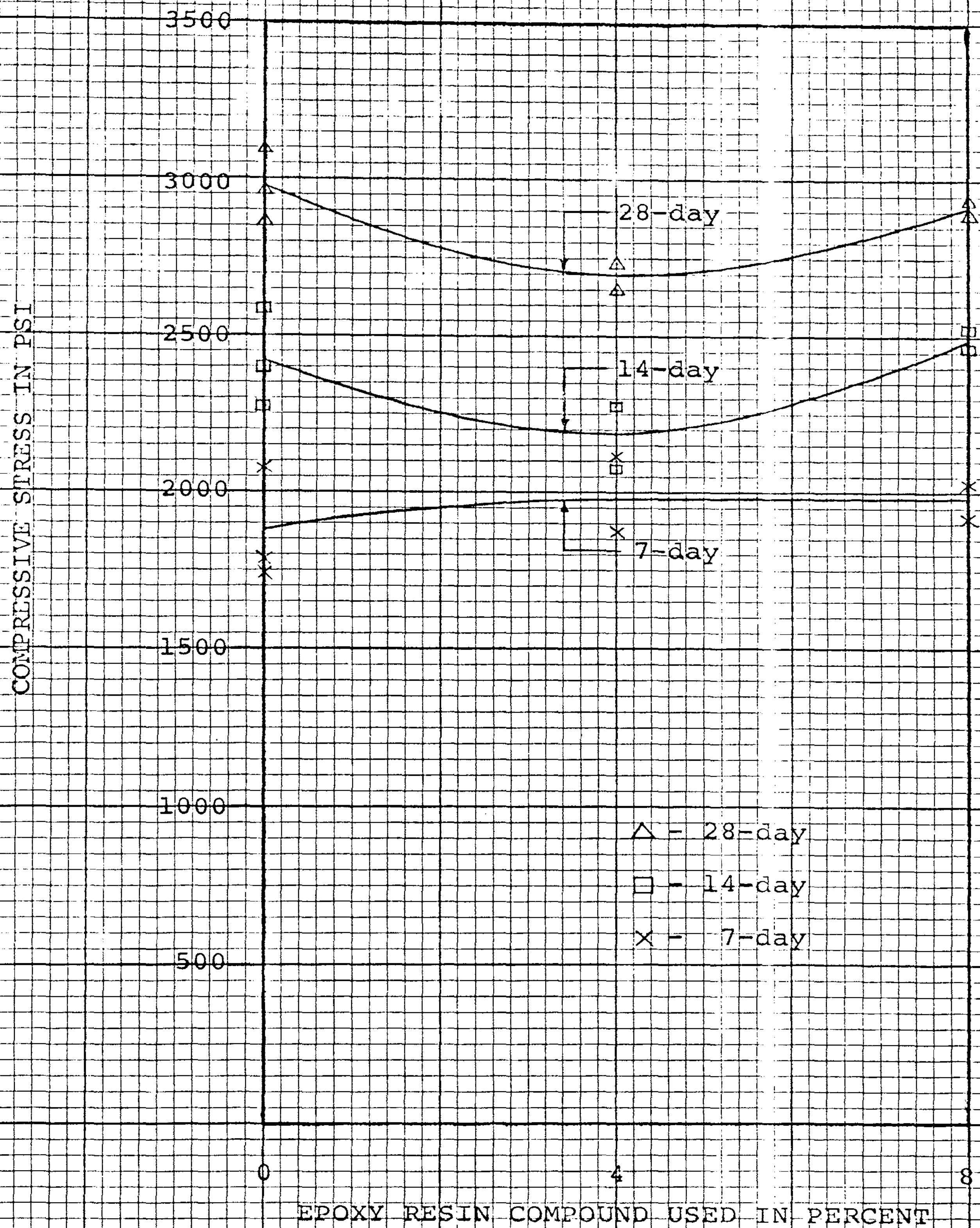

Fig. 1. Compressive Stress Vs. Admixture Content, Laboratory Curing Conditions

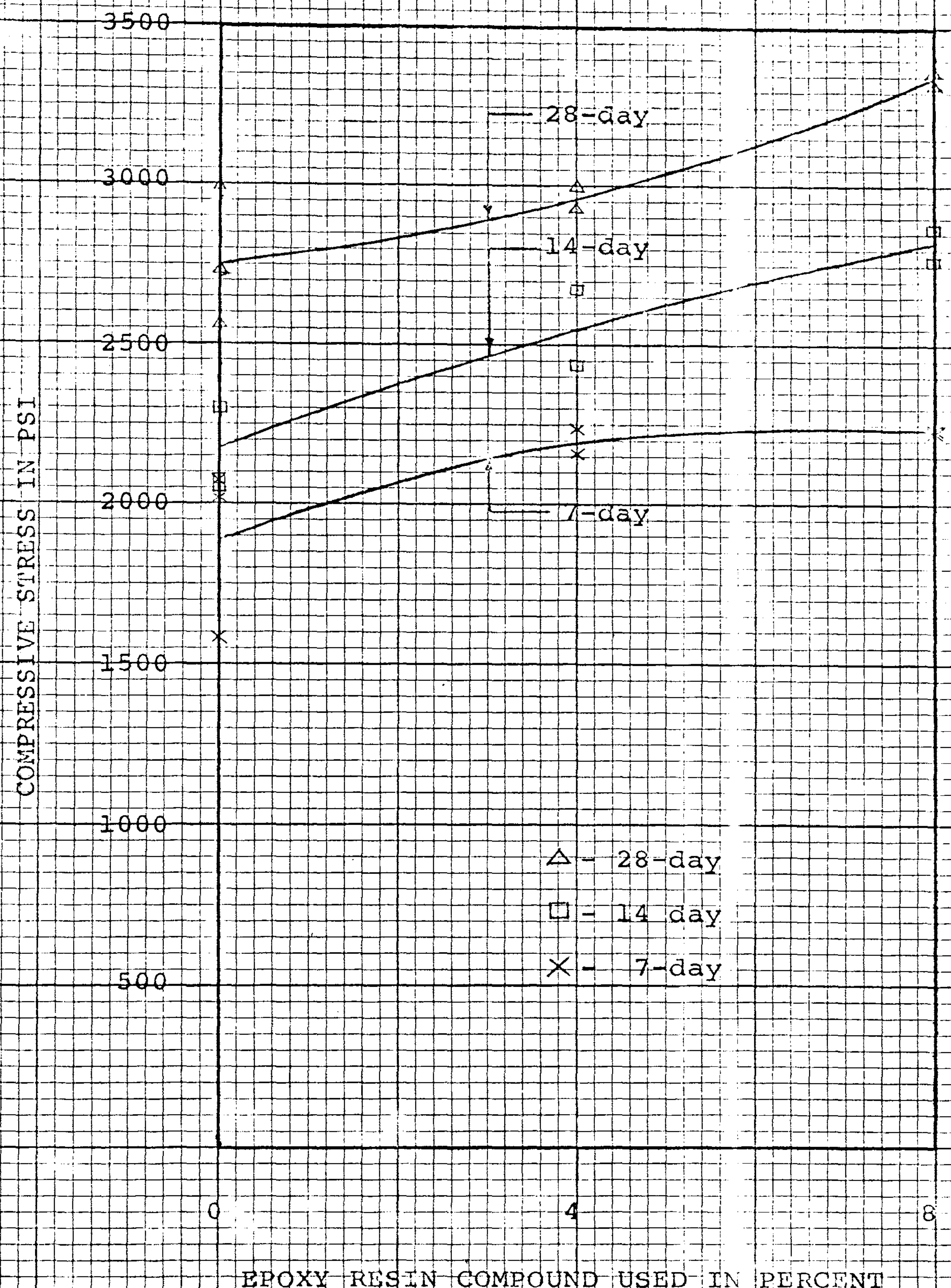

Fig. 2. Compressive Stress Vs. Admixture Content, Job Curing Conditions

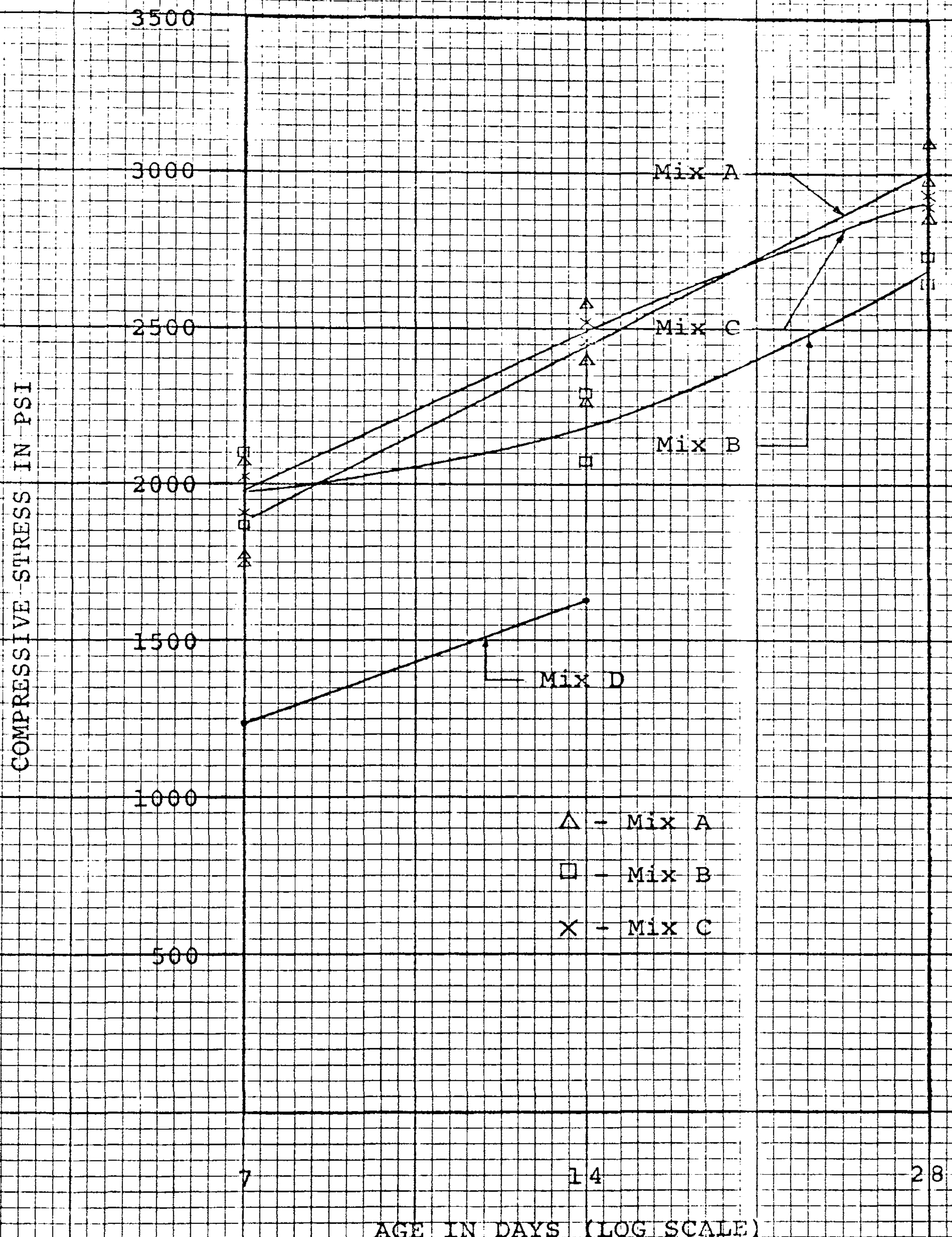

Fig. 3. Compressive Stress Vs. Age, Laboratory Curing Conditions

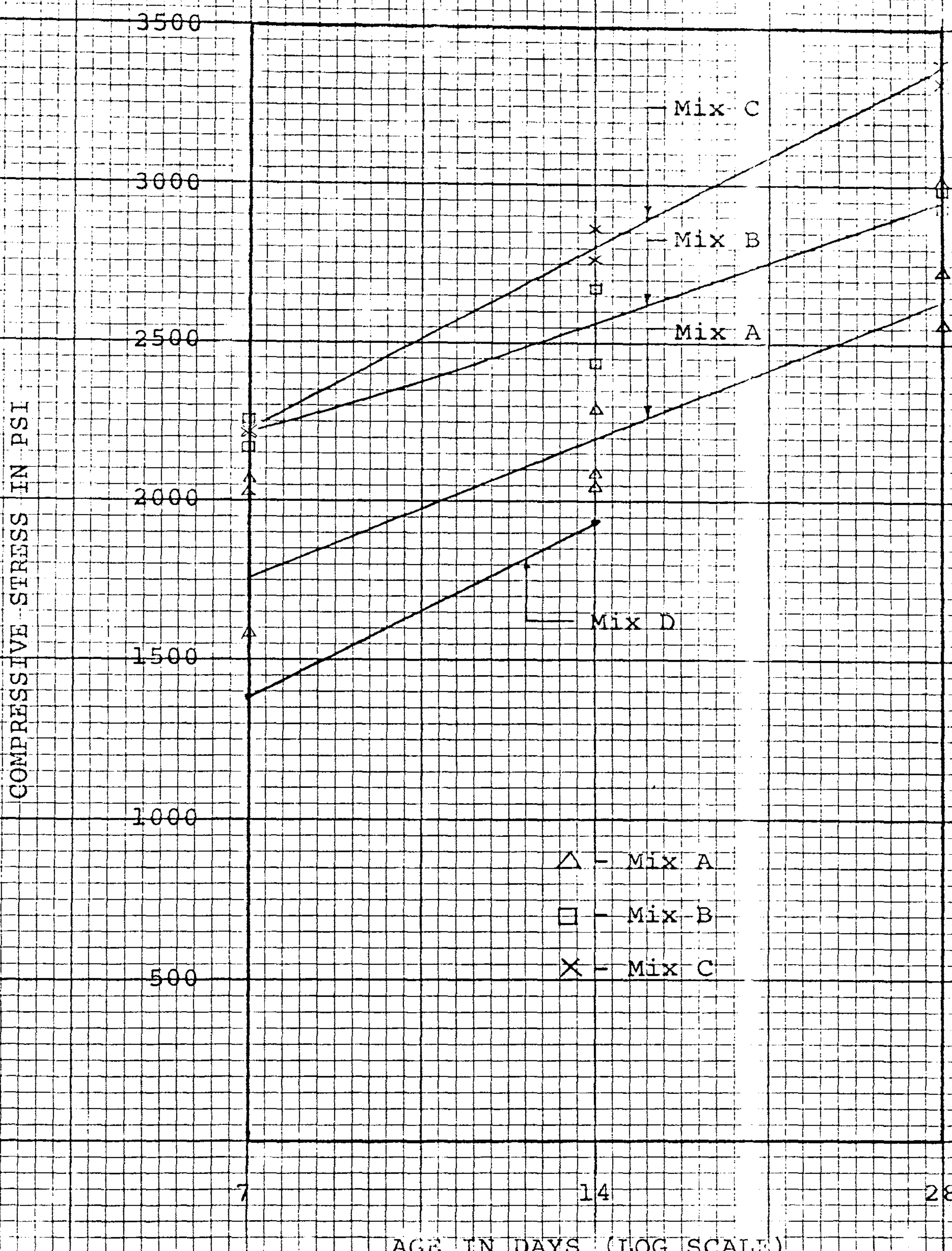

Fig. 4. Compressive Stress Vs. Age, Job Curing Conditions

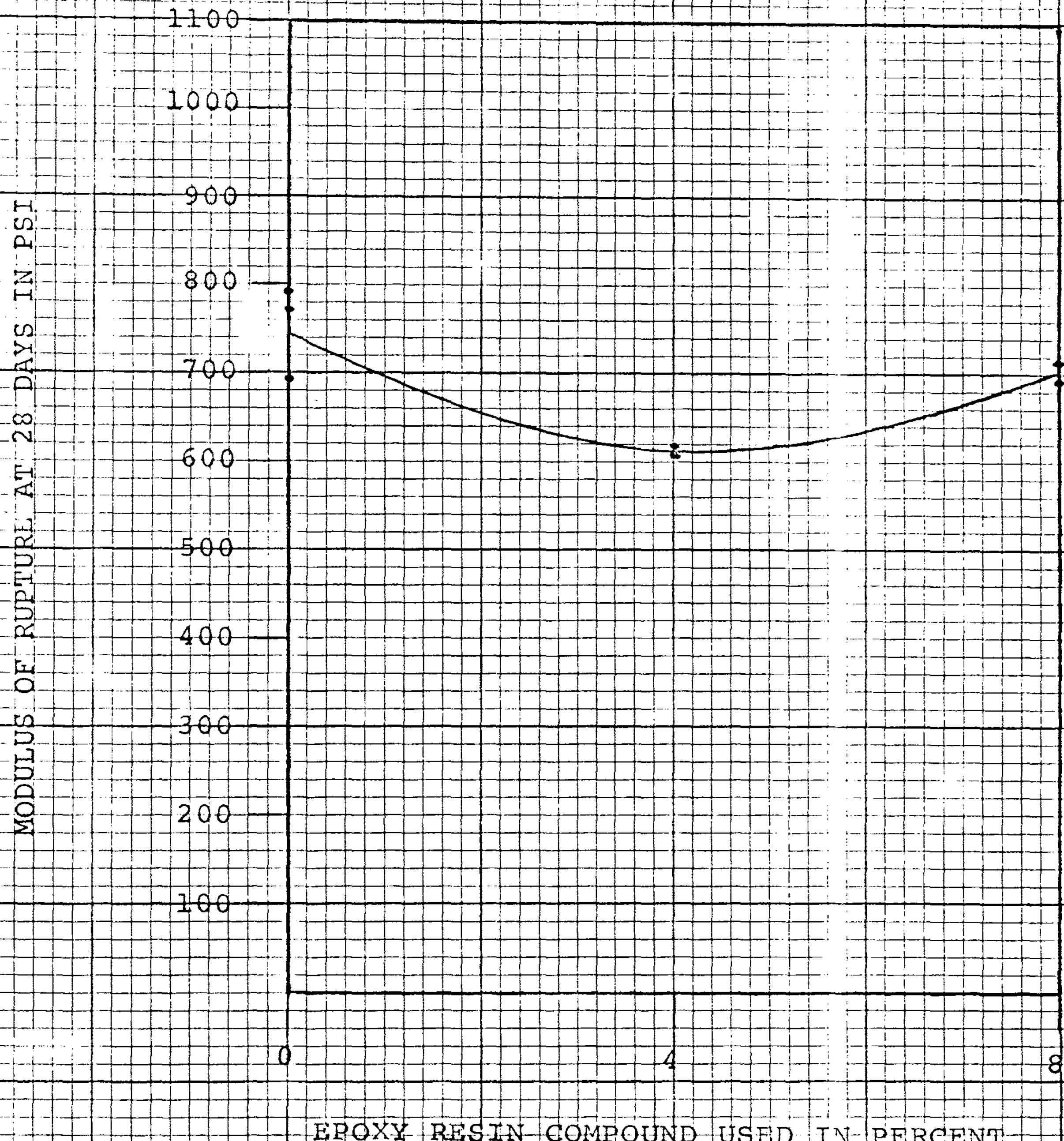

Fig. 5. Modulus of Rupture Vs. Admixture Content Laboratory Curing Conditions

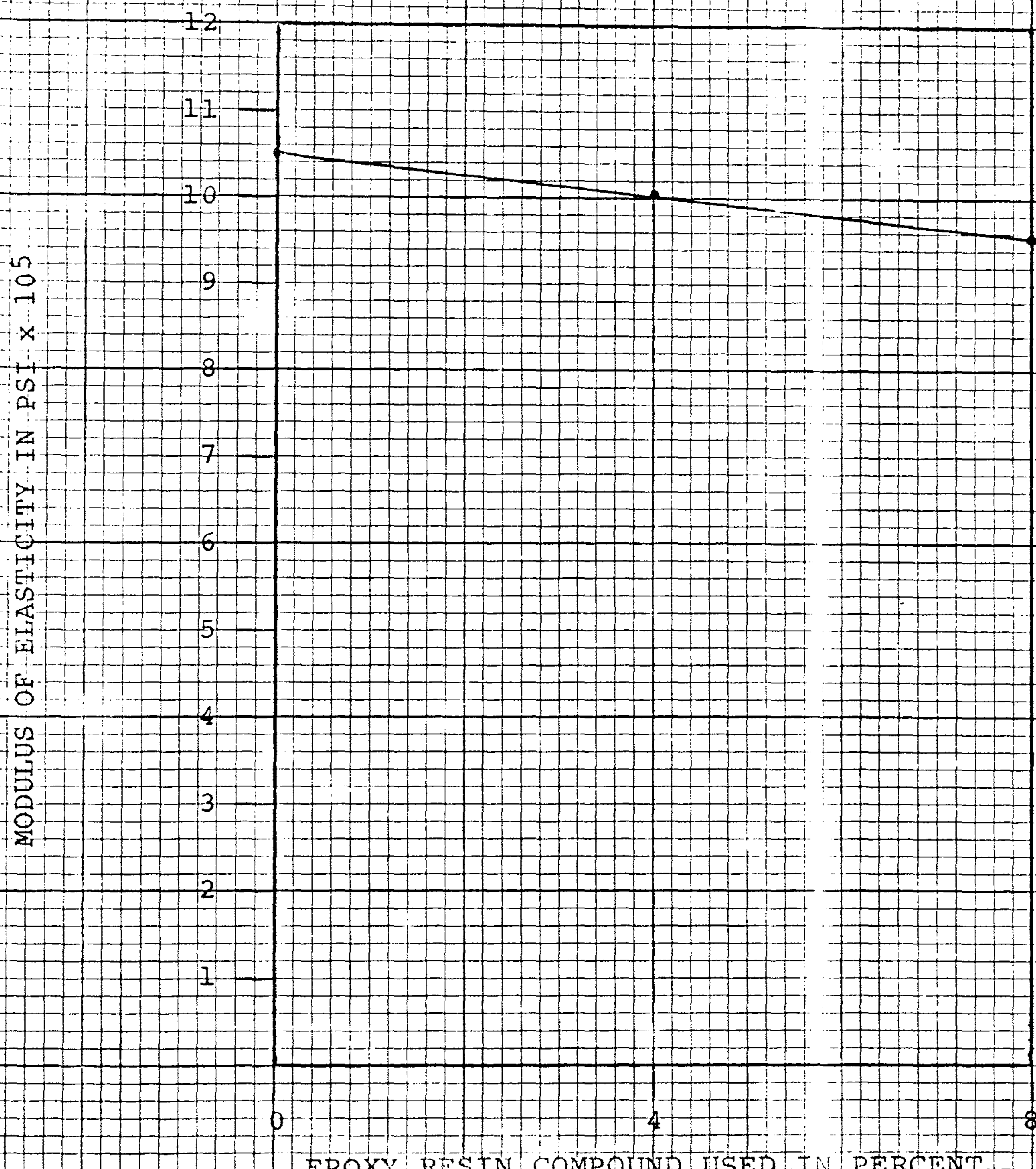

Fig. 6. Modulus of Elasticity at 28 Days Vs. Admixture Content, Laboratory Curing Conditions

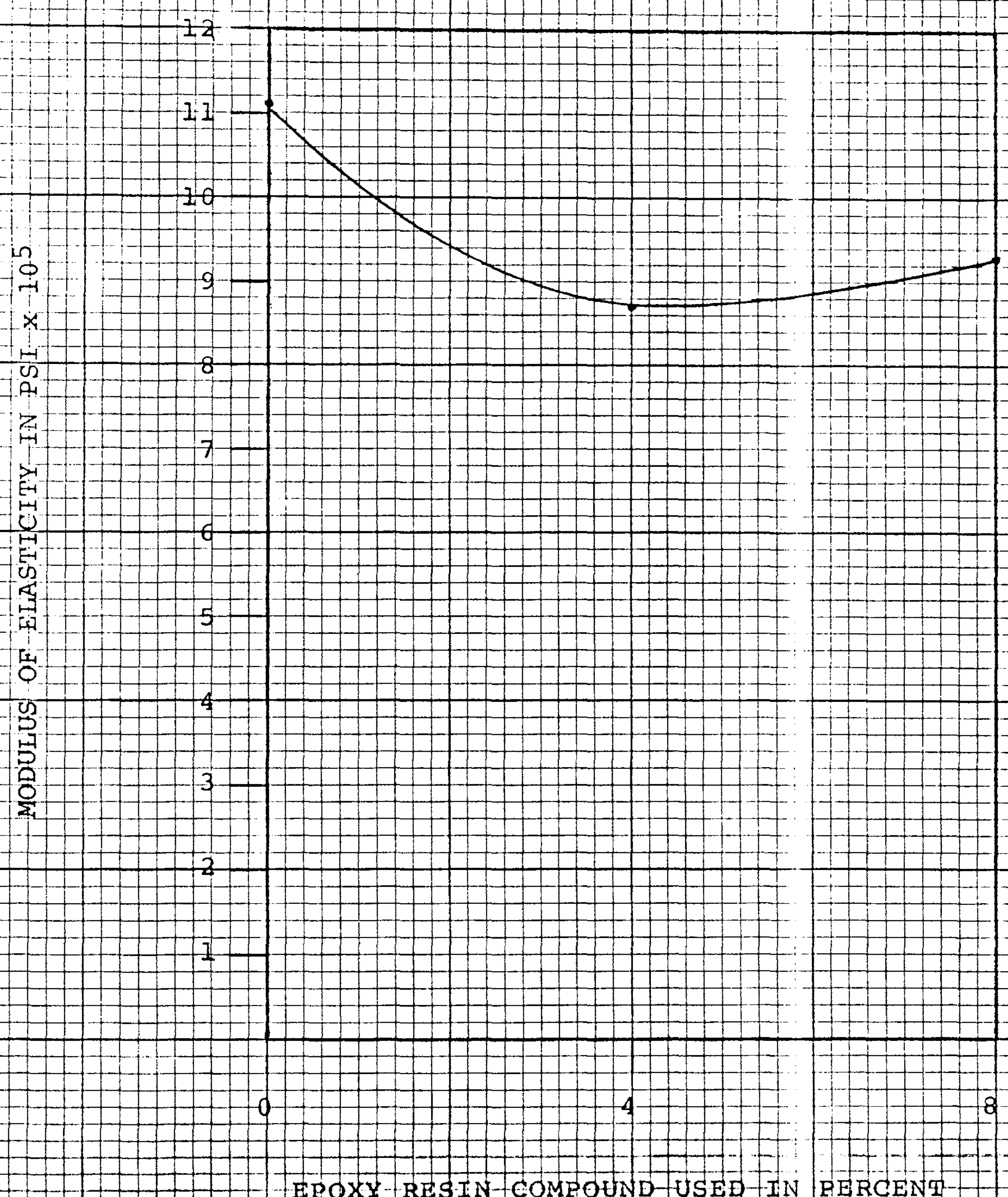

Fig. 7. Modulus of Elasticity at 28 Days Vs. Admixture Content, Job Curing Conditions

VI. CONCLUSIONS

Since there is very little existing data on this subject, there is no comparison with previous data. The conclusions drawn are based on the data from this series of tests. The results of the tests show that the compressive strength of concrete at various ages under job curing conditions definitely increased with an increase in percentage of admixture used. On the other hand, the compressive strength decreased slightly under laboratory curing conditions. This indicates that the curing of epoxy resin seems to be affected by moisture.

Figures 3 and 4 show that the compressive strength of Mix A specimens at various ages under laboratory curing conditions is much higher than that under job curing conditions as is usually the case. But the reverse effect is observed for specimens having admixture.

Like the compressive strength under laboratory curing conditions, the modulus of rupture also generally decreases because all beams for flexural strength tests were placed in the moisture room until the age of 28 days. Both the B and C mixes exhibit a decrease in strength when compared with Mix A.

As is expected, the modulus of elasticity of Mixes B and C specimens decreases in comparison to Mix A under both laboratory and job curing conditions because the epoxy resin itself has a low modulus of elasticity ranging from 400,000 to 600,000 psi (3).

The elastic modulus of concrete of the strength range in this investigation should be approximately 2,700,000 psi. The measured values for Mix A of 1,110,000 psi for the job curing conditions and 1,050,000 psi for the laboratory curing conditions are low. This is probably due to the method of measurement. In this investigation, the deformation was not measured directly from the cylinder. The measurement was obtained by the Ames dial placed against the lower platform. The reading was affected by the sulphur compound cylinder cap which had a low elastic modulus itself and the extension of the steel posts of the compression machine under applied load. Since the investigation is on the basis of comparison and the same measuring method was used for all mixes, the comparisons were apparently not affected by the difference between the actual and the measured modulus of elasticity.

Mixing procedure for Mix B and C was changed for Mix D which has the same percentage of admixture as Mix C. Test results show that the compressive strength at 7 days of Mix D specimens is only 62 per cent of Mix C and the compressive strength at 14 days is approximately 67 per cent of Mix C under the same curing conditions. The low strength is attributed to the inadequate mixing of epoxy resin and aggregate. The mixing time was limited for Mix D because the epoxy resin had been mixed with curing agent before it was mixed with aggregate thus shortening the pot life. However, epoxy resin and sand can be mixed as long as desired for Mix C and B because the curing agent was added in the last step.

Epoxy resins are highly adhesive materials but there was no problem in cleaning equipment for the small percentages used in this investigation. However, releasing agent might be necessary to clean the equipment in the case of a high percentage of epoxy used in the mixture.

APPENDIX

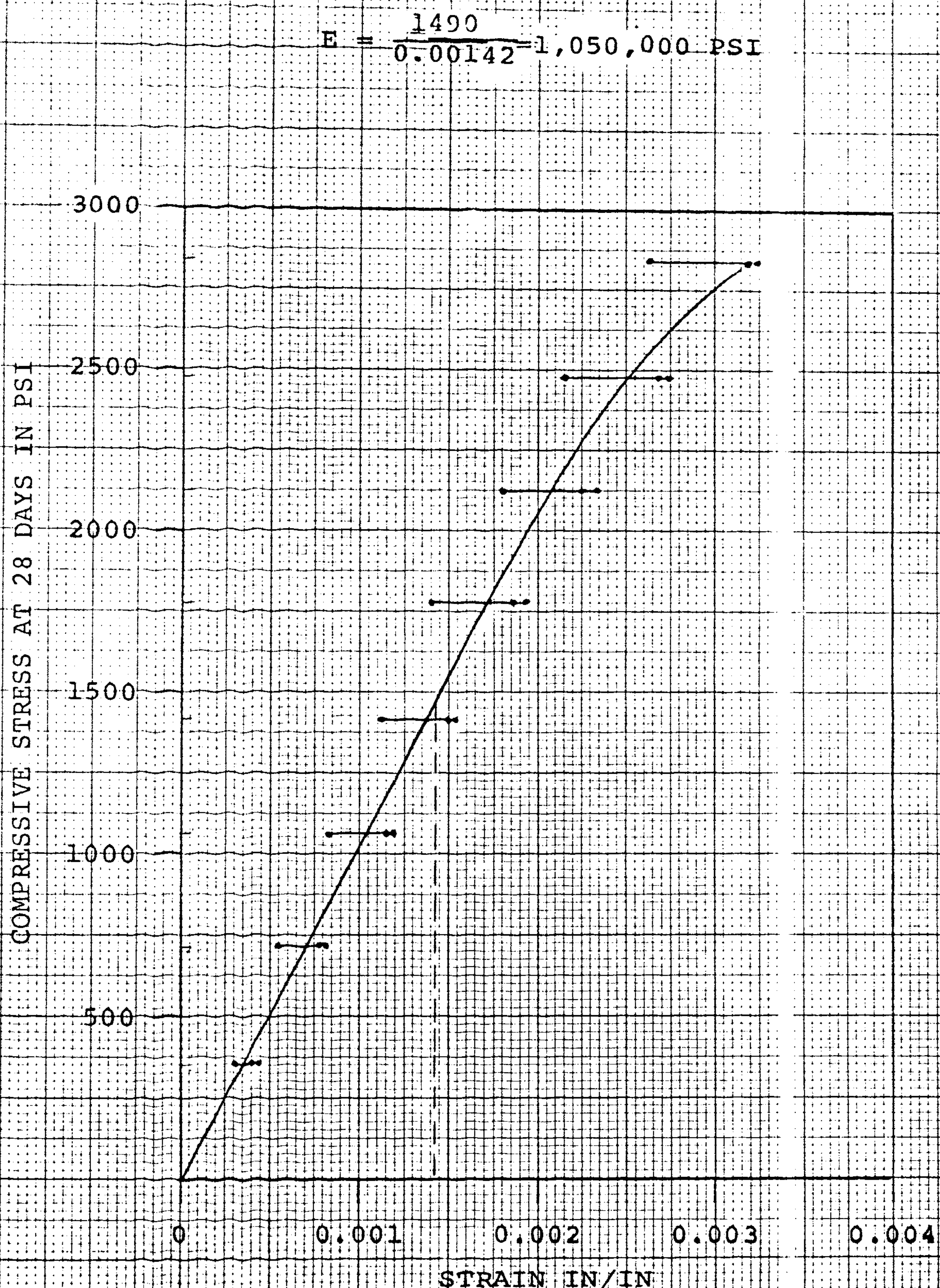

Fig. 8. Stress Vs. Strain Curve, Mix A, Laboratory Curing Conditions

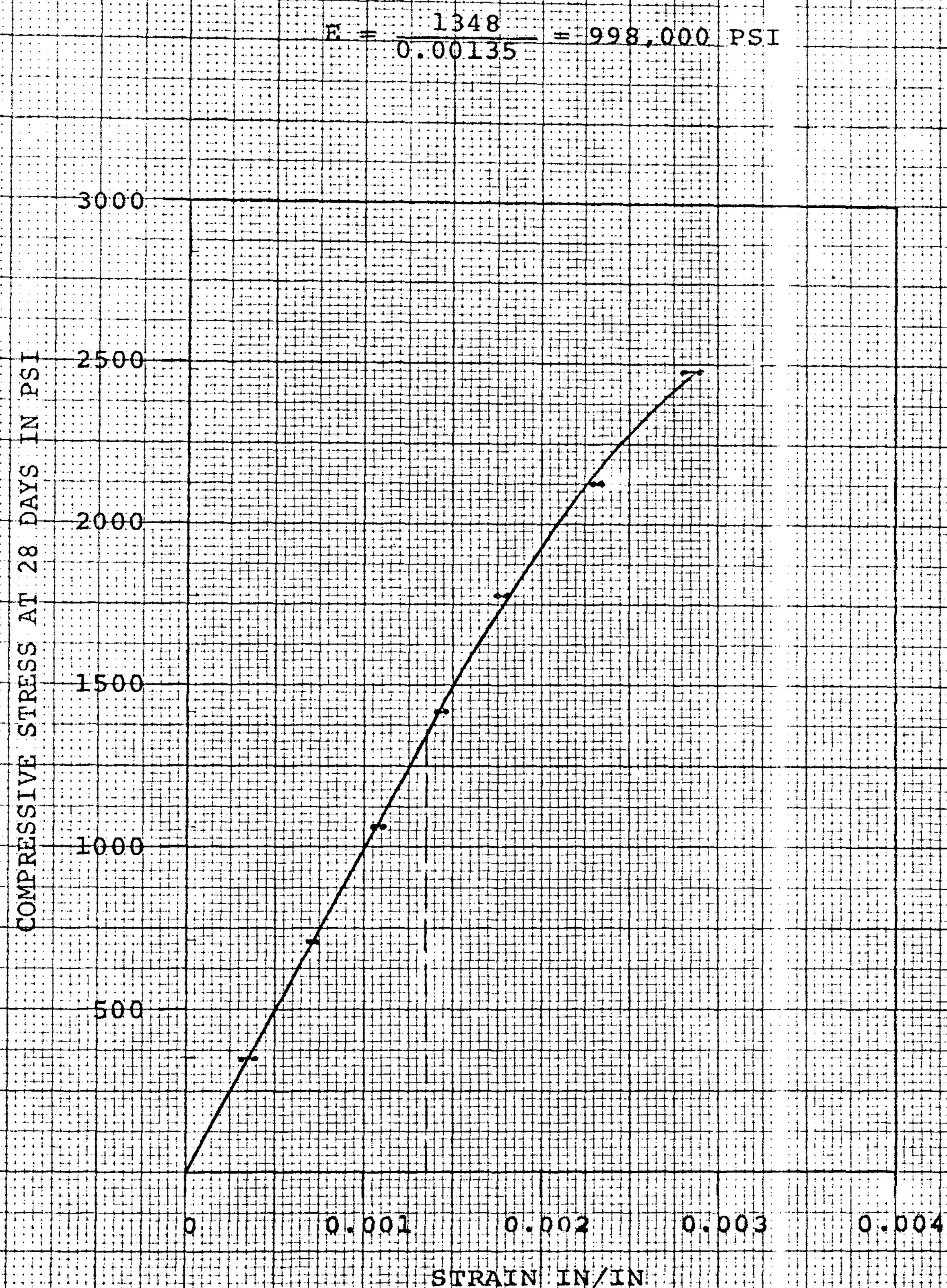

Fig. 9. Stress Vs. Strain Curve, Mix B, Laboratory Curing Conditions

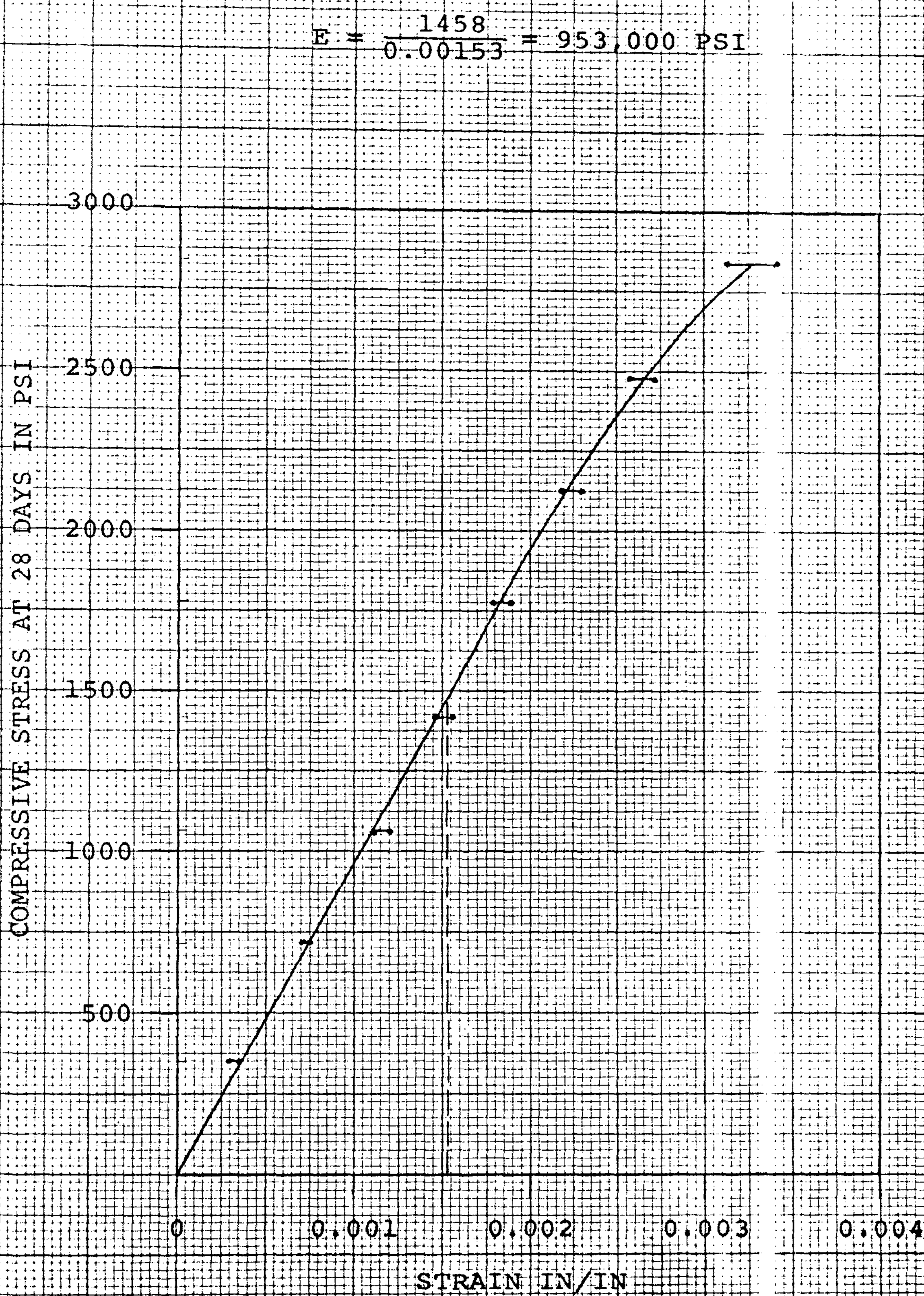

Fig. 10. Stress Vs. Strain Curve, Mix C, Laboratory Curing Conditions

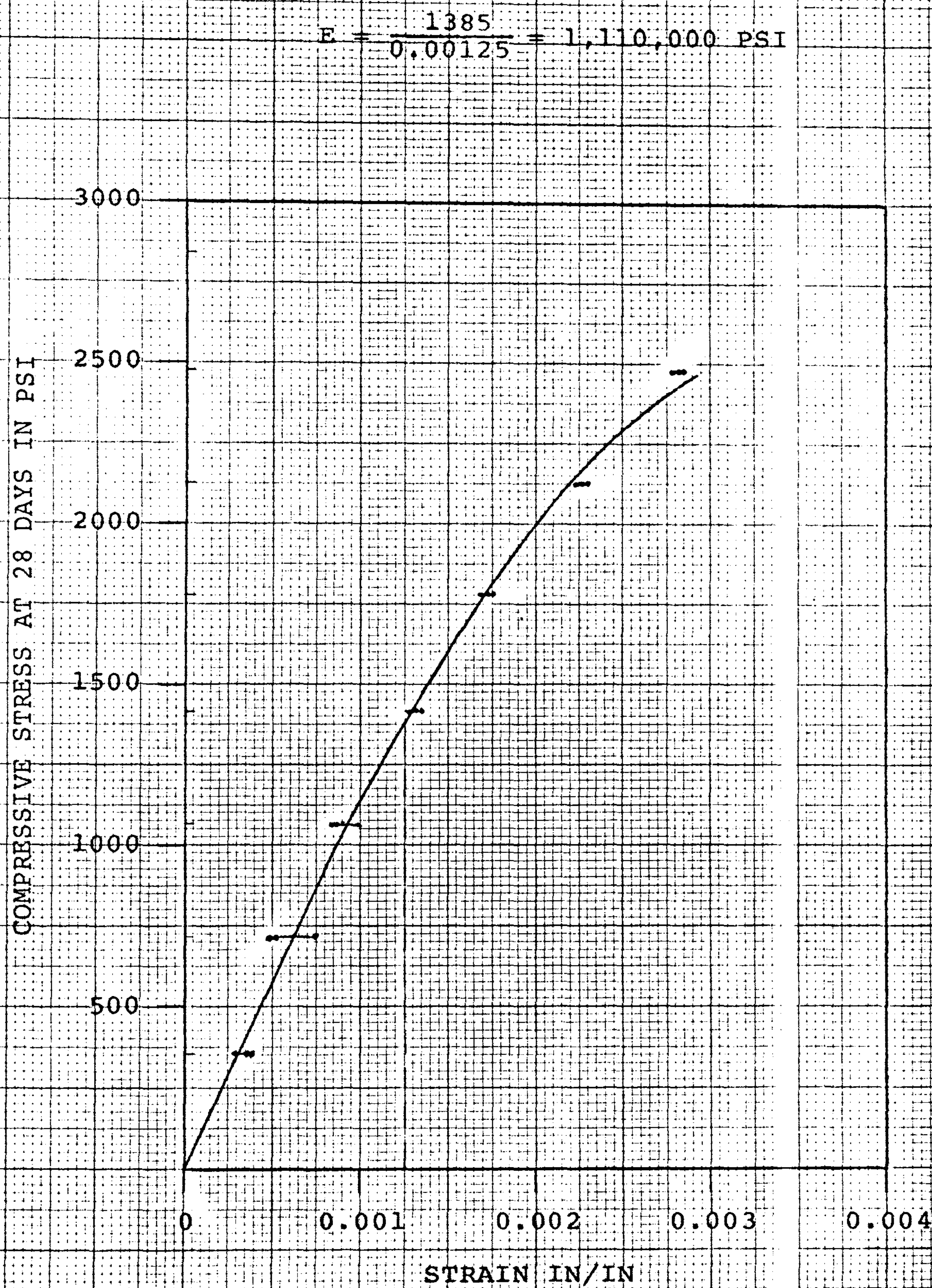

Fig. 11. Stress Vs. Strain Curve, Mix A,
Job Curing Conditions

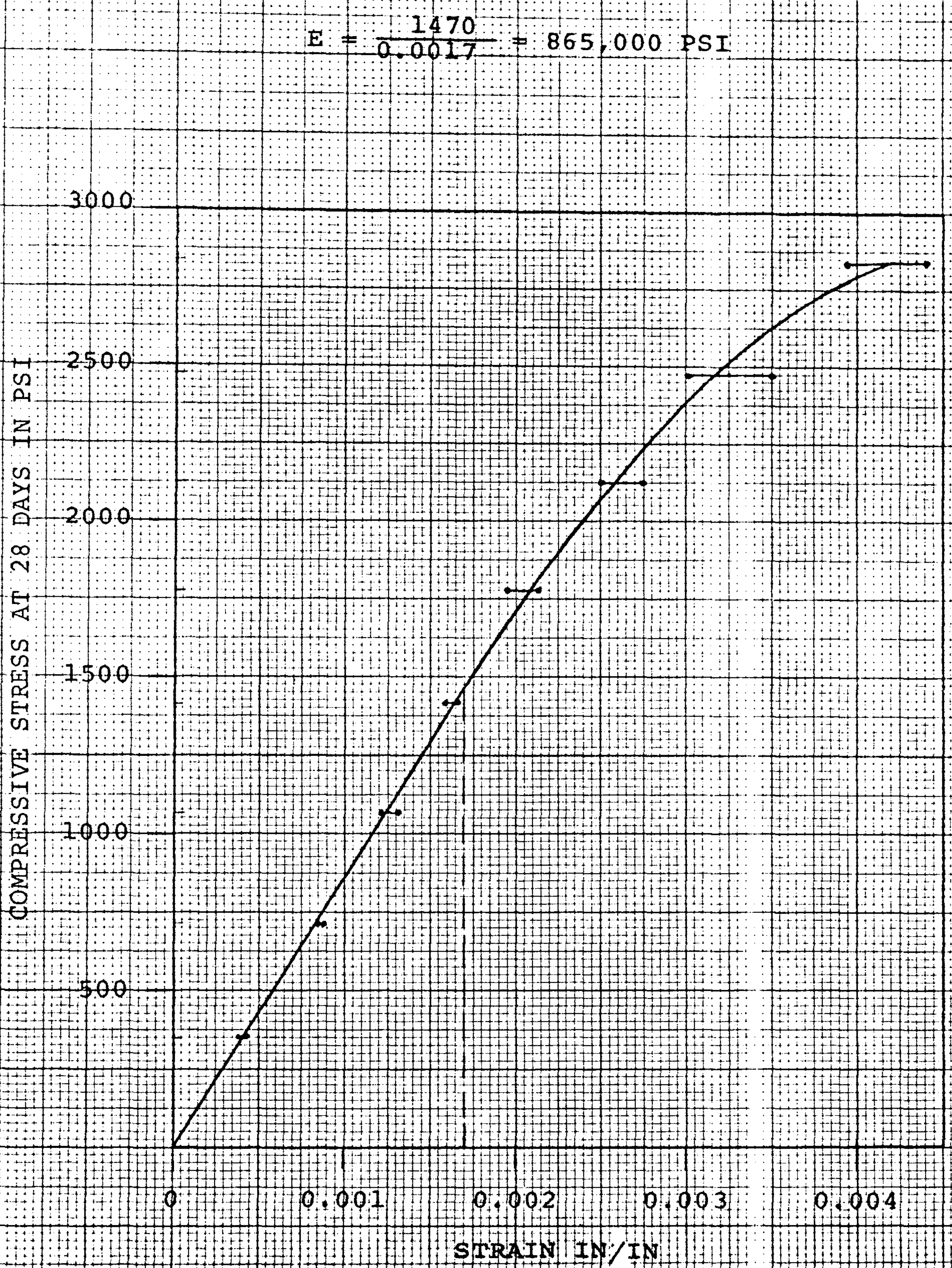

Fig. 12. Stress Vs. Strain Curve, Mix B, Job Curing Conditions

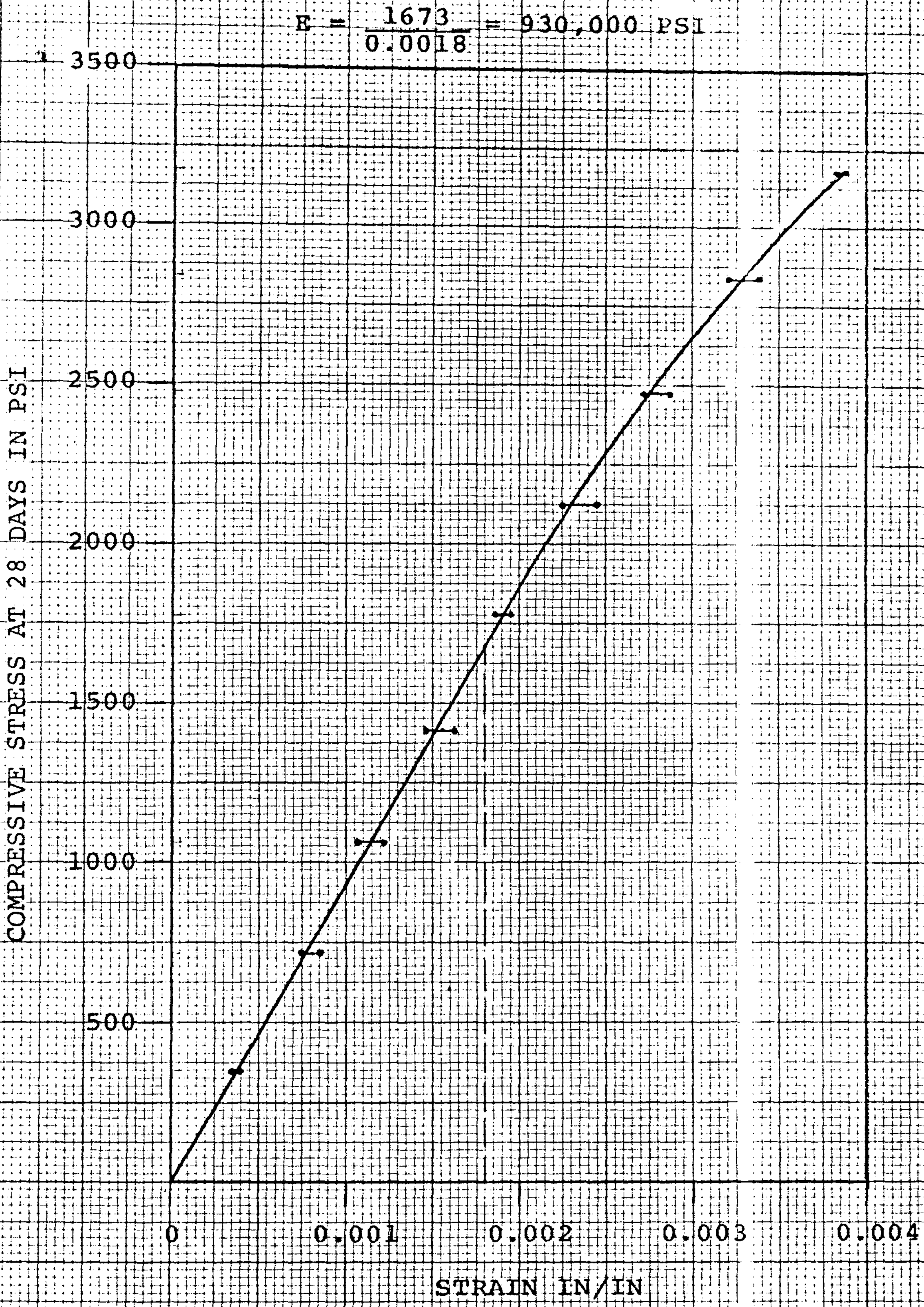

Fig. 13. Stress Vs. Strain Curve, Mix C, Job Curing Conditions

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